

# Satellite Retrievals in Chesapeake Bay Using Various Processing Approaches

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## Objective:

The l2gen processing approaches of Siegel, Arnone and Stumpf were evaluated against in situ observations in Chesapeake Bay. The objective of this analysis was to examine the level of agreement between the various approaches and in situ data, as well as the degree to which they capture spatial variability in a turbid estuary such as Chesapeake Bay.

## Methods:

In situ observations providing bay-wide coverage were obtained primarily from research and monitoring cruises conducted by the NSF LMER-TIES program and the Chesapeake Bay Program. The most cloud free image from each cruise period was processed using standard l2gen processing and the four test methods (Siegel7/8, Arnone, Stumpf and Stumpf with 412 iterations). Images were processed with the following masks: EPSILON, LAND, SUNGLINT, HIGHLT, CLDICE, and STRAYLIGHT. Thirteen scenes were processed for comparison with twelve sets of bay-wide in situ observations made in 1998 and 1999. In situ observations and satellite pixels used were confined to the region shown in blue in Figure 1. The region of the Bay north of 38.83°N was excluded, as well as stations and pixels close to shore.

An additional axial transect in the Bay and an offshore transect of chlorophyll measurements (ONR-funded cruises) also were available for comparison with the results from each processing method.

## Results:

### Regional Comparisons

Chesapeake Bay was divided into four regions by latitude (Figure 1). The mean and variance were calculated for each region. Pixels in which no chlorophyll value was returned ( $\text{chl} = 0 \text{ mg/m}^3$ ), as well as those pixels in which the maximum value was returned ( $\text{chl} > 64 \text{ mg/m}^3$ ), were excluded from the statistics. The number of in situ observations and the number of valid pixels returned for each region by each method are summarized in Table 1. The results of the regional comparisons are shown in Figure 2 (standard processing results not shown).

### Transect Comparisons

In situ observations and individual pixels were compared along an axial transect through the Bay in July 1998 (Figure 3), a lateral transect in the Bay that was occupied seven times in 1998 and 1999 (Figure 4), and an offshore transect extending from Delaware Bay across the continental shelf in September 1998 (Figure 5).

## Conclusions

### Regional Comparisons

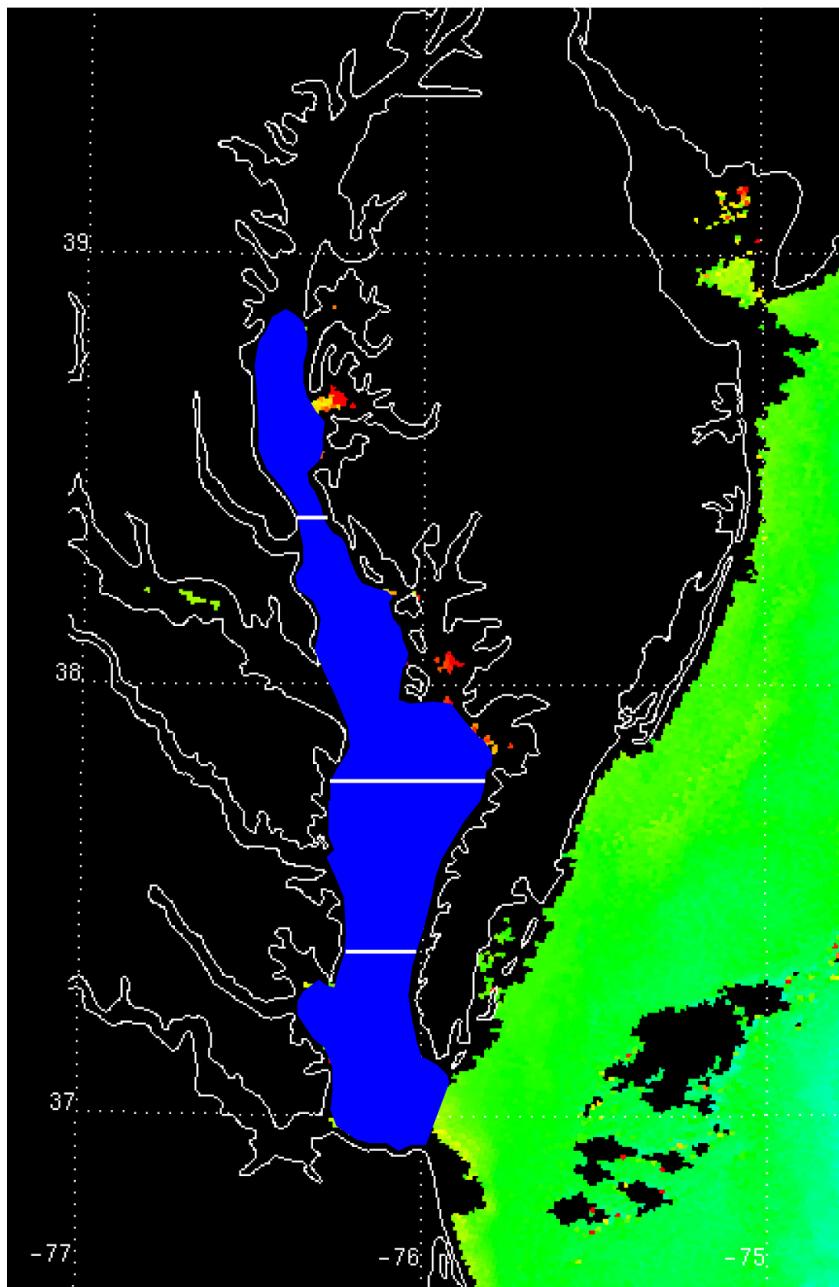
- Although the results from standard processing are not shown in most figures, the four approaches greatly improve the chlorophyll estimates relative to standard processing. In general, the number of valid pixel retrievals is increased and the number of maximum values ( $> 64 \text{ mg/m}^3$ ) returned is greatly reduced.
- The Stumpf412 approach provides the most accurate estimates of mean surface chlorophyll (and variance) under conditions in which chlorophyll concentrations are near or below the annual mean ( $\sim 10 \text{ mg/m}^3$ ) for the Bay. The other approaches often overestimate both the mean chlorophyll and the variance within each region, with the greatest overestimate occurring in the northern region of the Bay.
- When chlorophyll concentrations are relatively high ( $> 10 \text{ mg/m}^3$ ) in the mid and lower Bay, such as the bloom conditions captured in the March and April 1998 data, the Stumpf412 approach misses much of this variability and greatly underestimates both the mean chlorophyll concentration and the variance within each region. The Siegel, Stumpf and Arnone approaches appear to do better under high chlorophyll conditions in the mid and lower Bay, but still return overestimates of chlorophyll when concentrations are low ( $< 10 \text{ mg/m}^3$ ).

### Transect Comparisons

- The axial transect shows that the Stumpf412 approach is the only method to return reasonable values in the upper Bay. The mid-Bay maximum is underestimated by the Stumpf412 approach and better represented by the other approaches. In the Lower Bay, the Stumpf412 approach again returns the most reasonable values.
- The lateral transects again show that the Stumpf412 approach often does well when the chlorophyll concentration is less than  $10 \text{ mg/m}^3$ , but underestimates chlorophyll at higher concentrations.
- In the offshore waters, all approaches generally overestimate chlorophyll. The overestimate decreases with distance offshore, leveling out at about 1.5 to 2 times the observed values. In these less turbid waters, the Siegel7/8, Arnone and even the standard processing do better in estimating chlorophyll than the Stumpf and Stumpf412 approaches.

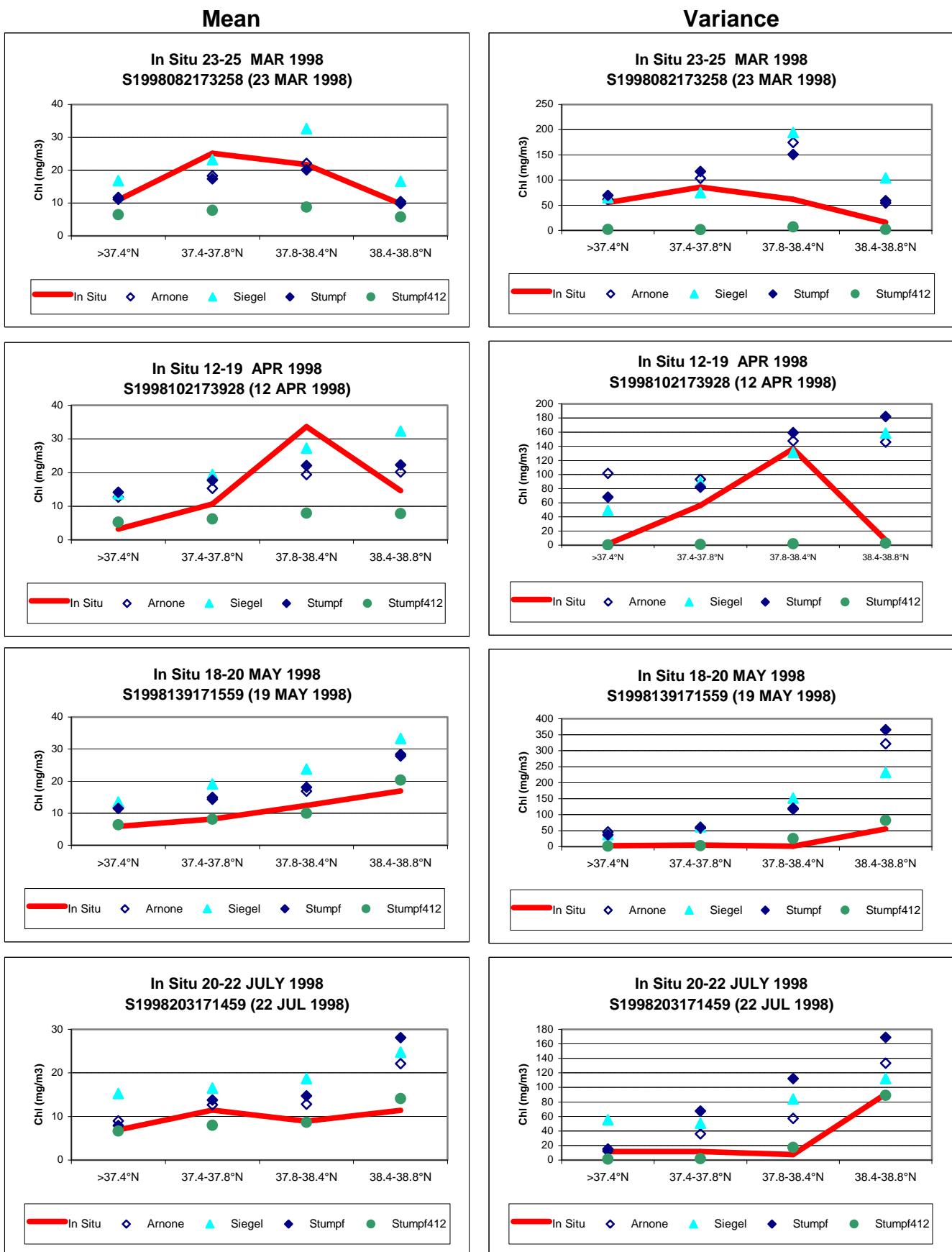
## Overall

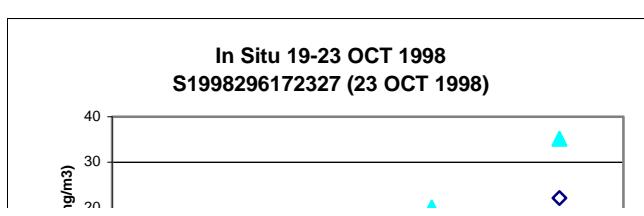
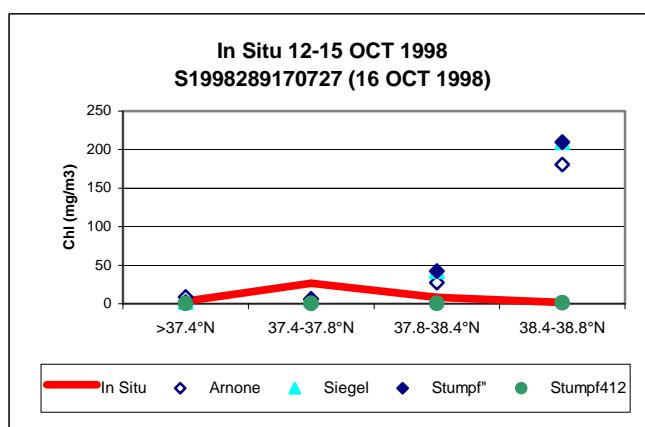
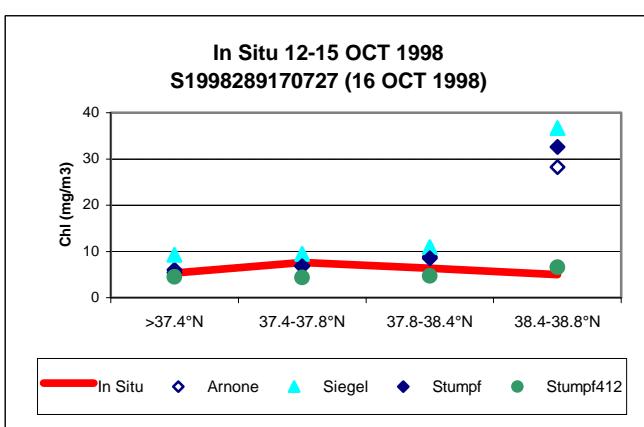
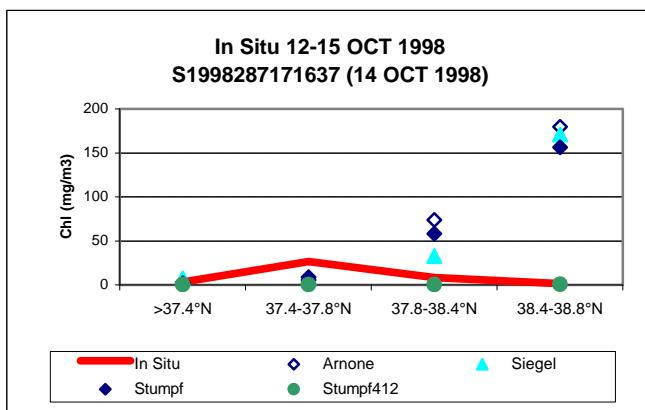
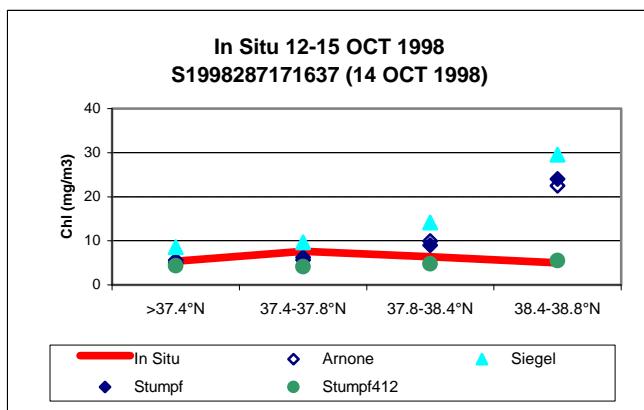
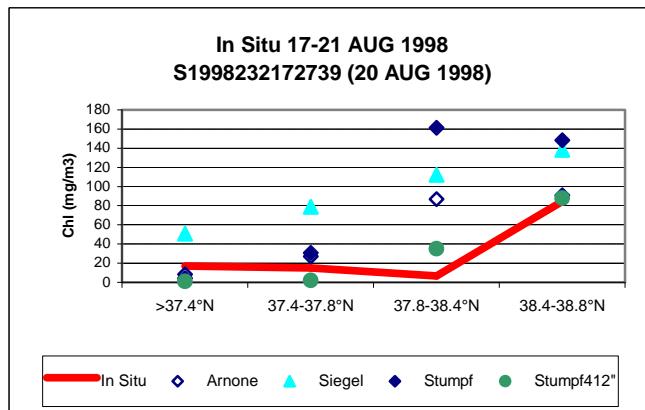
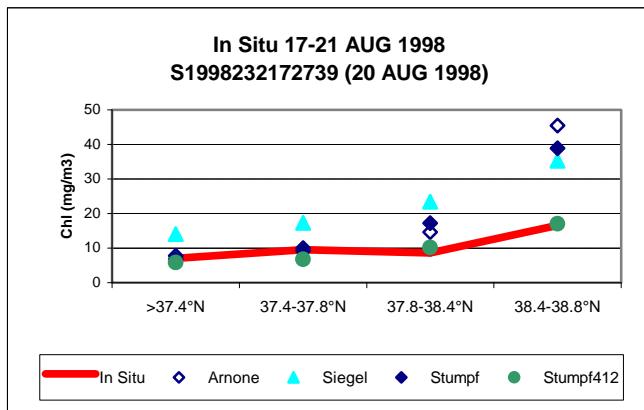
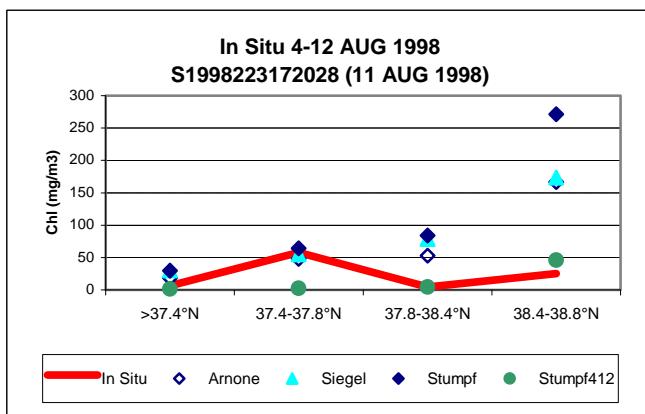
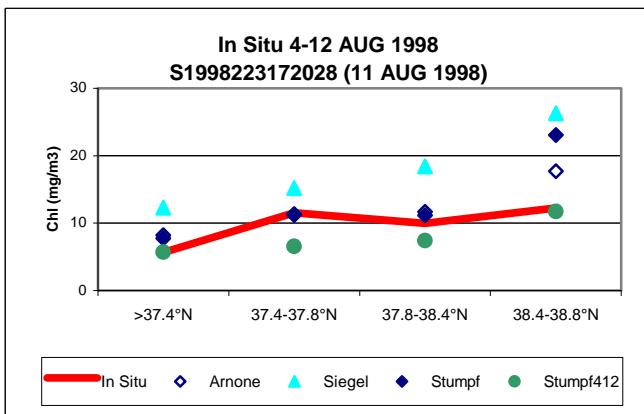
In general, the comparisons are inconclusive with regard to the best option for estuarine and coastal waters. The Stumpf412 approach provided the most reasonable estimates of surface chlorophyll within the Bay when chlorophyll concentrations were below the annual mean of about  $10 \text{ mg/m}^3$  and spatial variability was low, and also did well in the more turbid northern Bay. However, the Stumpf412 also appeared to dampen out any spatial variability in chlorophyll concentration. In the less turbid waters outside of the Bay, the Siegel and Arnone approaches appear to provide more accurate estimates of surface chlorophyll.

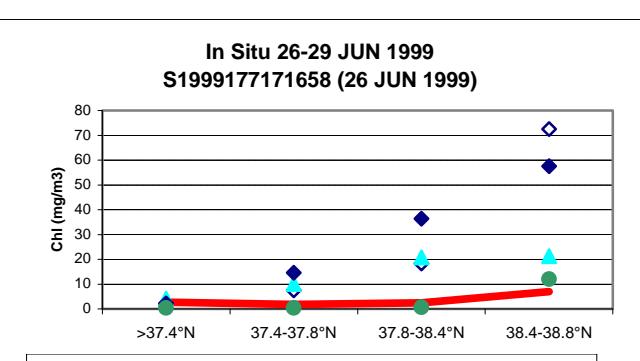
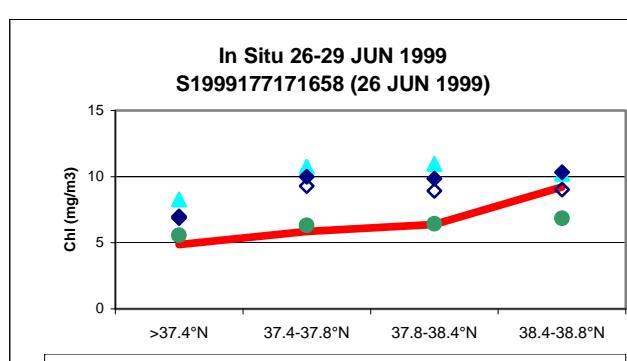
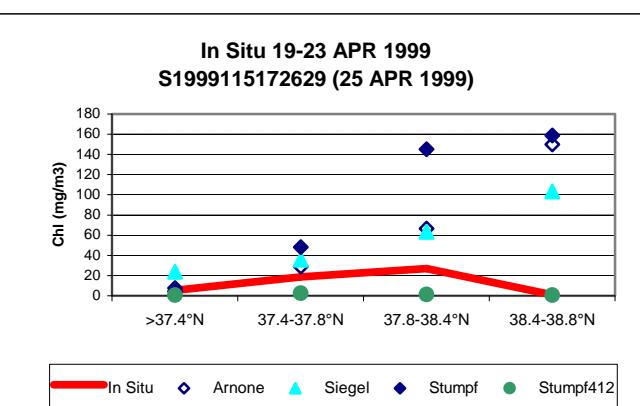
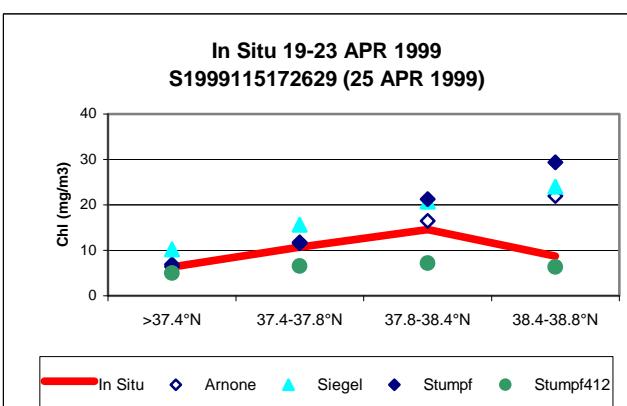
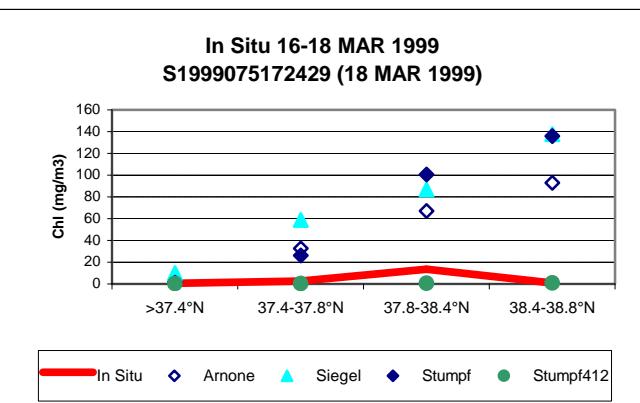
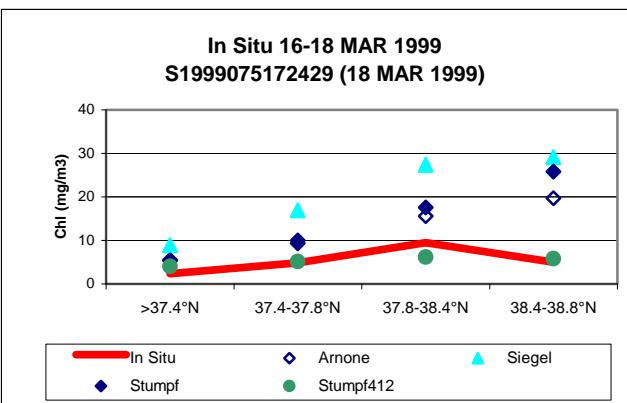
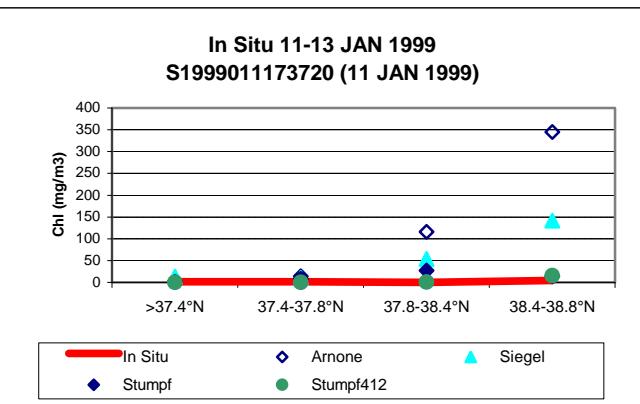
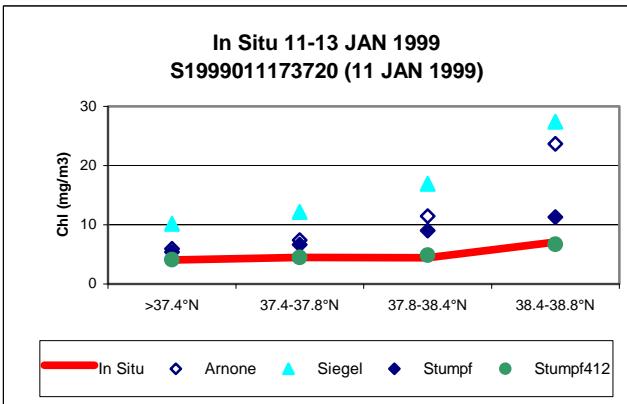
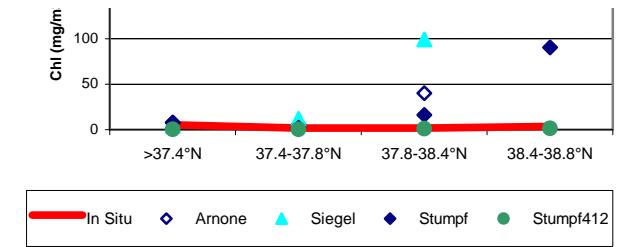
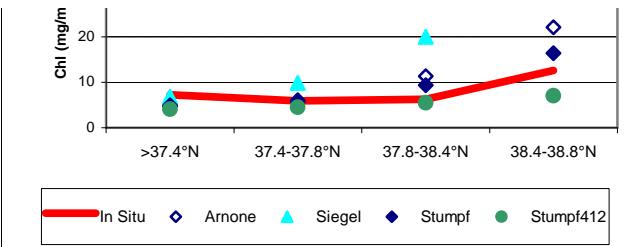


*Figure 1: Regional map of Chesapeake Bay and Adjacent offshore waters. Area in blue indicates region from which satellite chlorophyll values were extracted from SeaWiFS images. Horizontal lines delineate the four regions used in the regional comparisons.*

Figure 2: Regional comparisons of in situ observations and satellite retrievals within Chesapeake Bay using the processing approaches of Arnone, Siegel and Stumpf.







— In Situ    ♦ Arnone    ▲ Siegel    ♦ Stumpf    ● Stumpf412

— In Situ    ♦ Arnone    ▲ Siegel    ♦ Stumpf    ● Stumpf412

*Figure 3: Axial transect of stations within Chesapeake Bay. In situ observations were made on 10 July 1998 and the image (S1998192171648) represents conditions on 11 July 1998. Lower plot presents the same data on a smaller y-axis scale.*

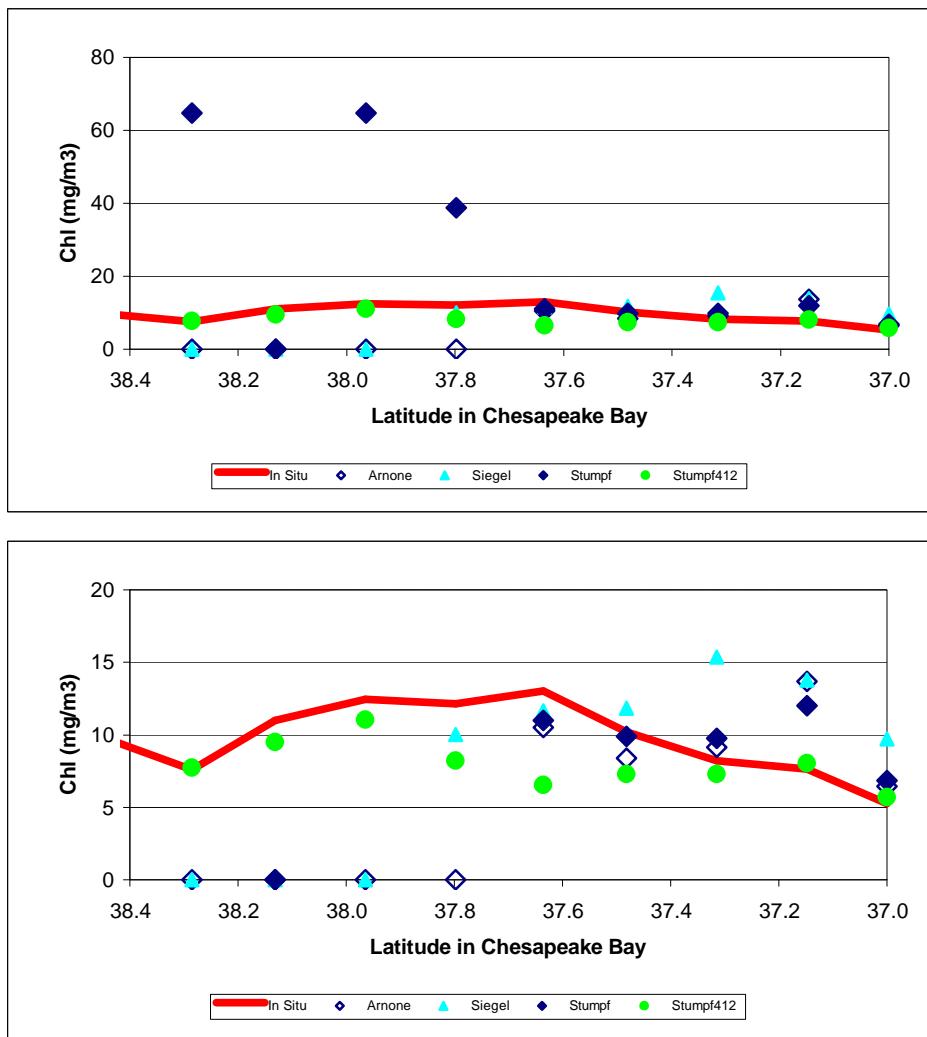
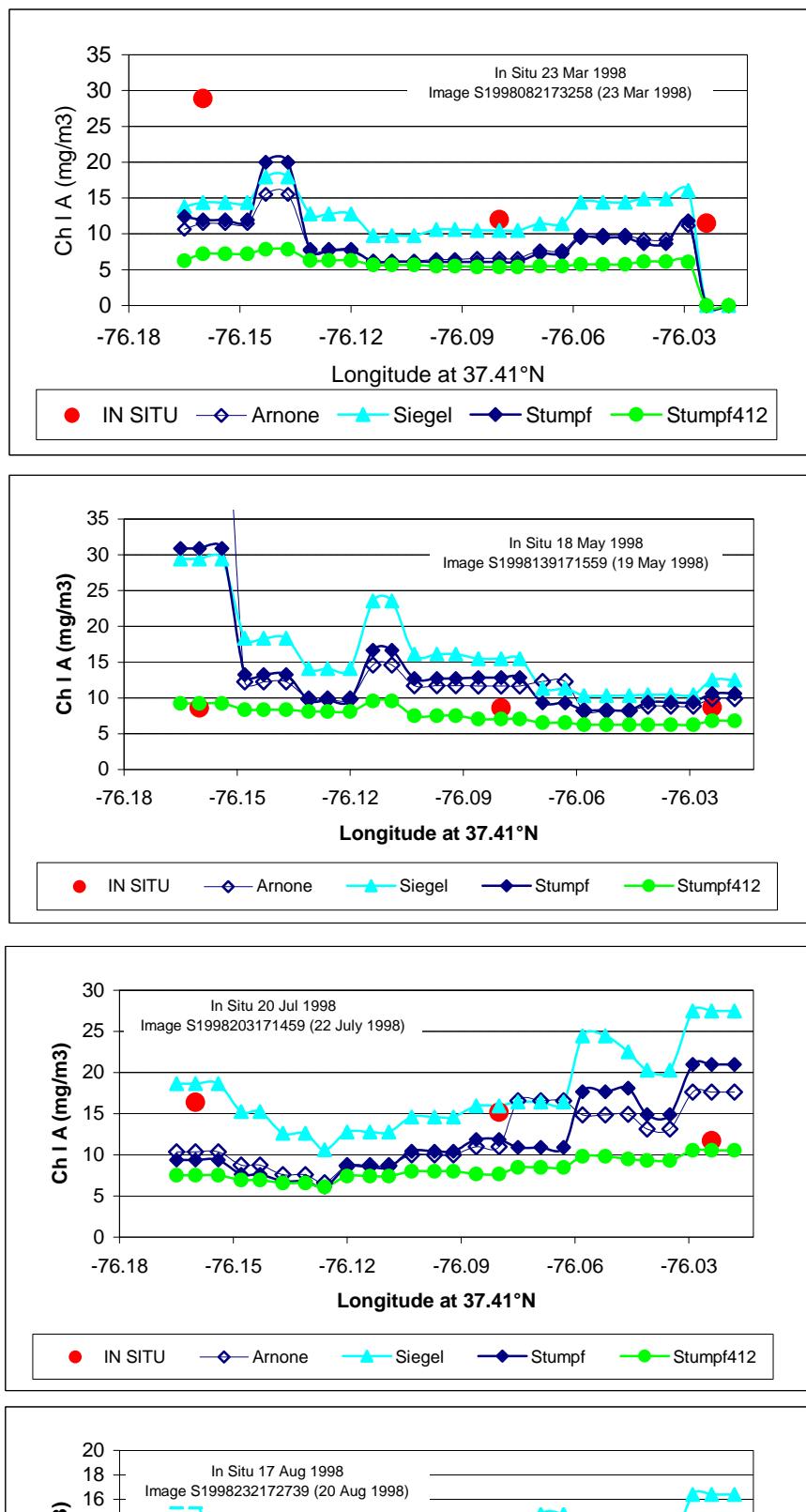
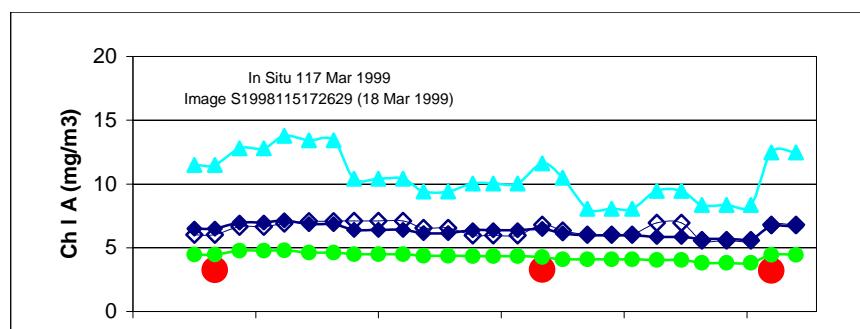
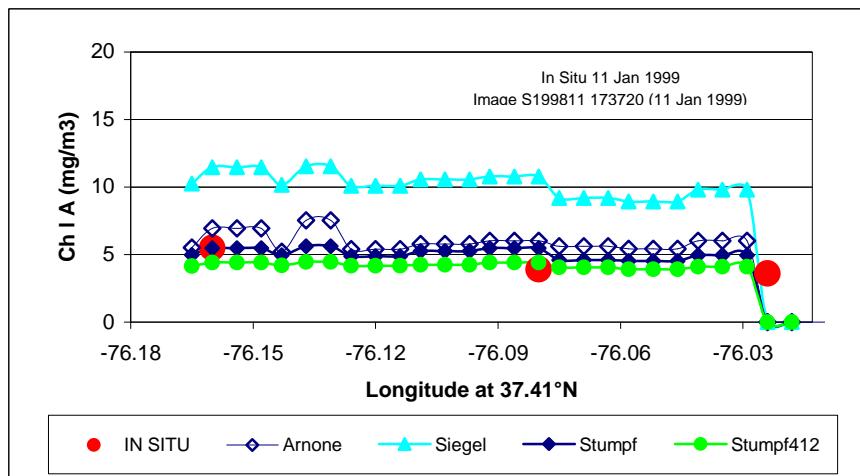
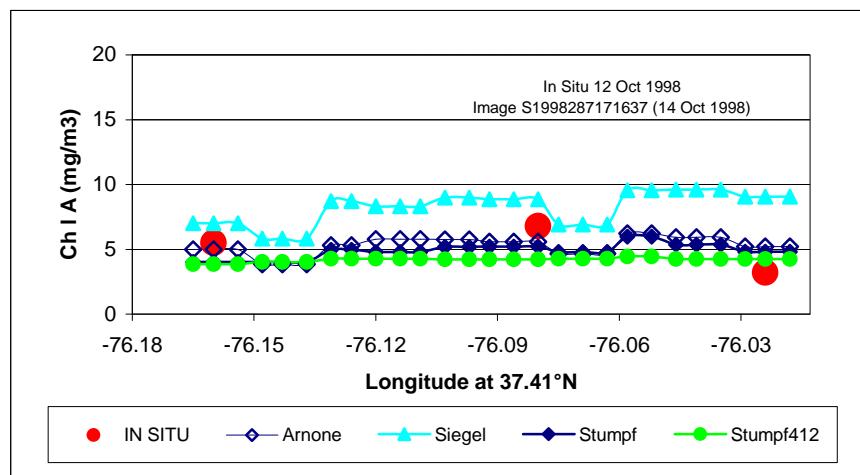
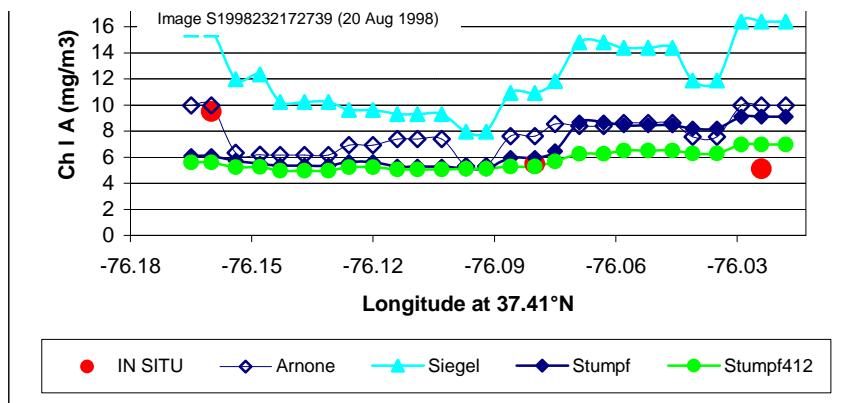
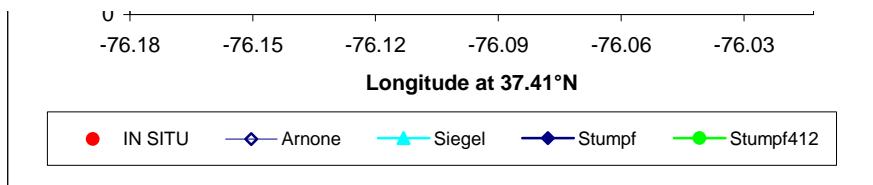


Figure 4: Comparison of *in situ* observations from three stations along 37.41°N in Chesapeake Bay with satellite retrievals along the same latitude band.







*Figure 5: Comparison of in situ observations and satellite retrievals along an offshore transect extending from the mouth of Delaware Bay to the southeast. In situ observations were made on 21-25 September 1998. The image (S1998267171208) represents conditions on 24 September 1998.*

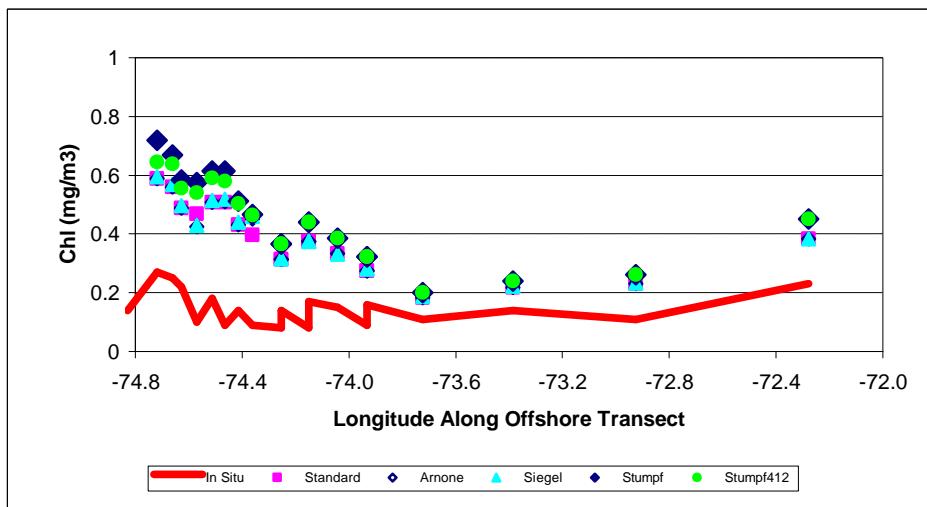


Table I: Number of in situ observations and satellite pixels used in the calculation of the mean and variance for each region of the Bay.

In Situ Dates	Image Day/Name	Region	In Situ		Image								
			# Observations	Standard		Arnone		Siegel		Stumpf		Stumpf412	
				# Pixels	>0	# Pixels							
23-25 Mar-98	23-Mar-98	38.4-38.8°N	7	396	297	380	374	396	390	374	368	380	380
CBP	S1998082173258	37.8-38.4°N	6	2430	315	2434	2184	2417	2157	2417	2217	2433	2433
		37.4-37.8°N	10	3570	1637	3570	3483	3561	3521	3556	3507	3561	3561
		<37.4°N	6	3617	2555	3612	3565	3617	3597	3617	3568	3617	3617
		Total	29	10013	4804	9996	9606	9991	9665	9964	9660	9991	9991
11-19 Apr-98	12-Apr-98	38.4-38.8°N	7	1044	149	1326	905	1378	1093	1621	1621	1507	985
TIES	S1998102173928	37.8-38.4°N	10	3411	549	3860	3344	4099	3927	4343	4343	4182	3622
		37.4-37.8°N	20	4303	947	4308	3236	4435	4374	4435	4435	4429	4044
		<37.4°N	14	4198	2748	4204	3644	4216	4196	4215	4215	4215	4135
		Total	51	12956	4393	13698	11129	14128	13590	14333	12786	14614	14614
18-20 May-98	19-May-98	38.4-38.8°N	7	88	21	185	82	142	111	248	64	837	793
CBP	S1998139171559	37.8-38.4°N	4	3553	1185	3712	3173	3785	3522	3744	3199	4028	3980
		37.4-37.8°N	10	4573	1931	4573	4338	4573	4443	4570	4415	4570	4570
		<37.4°N	7	4307	3251	4307	4205	4307	4307	4307	4262	4307	4307
		Total	28	12521	6388	12777	11798	12807	12383	12869	11940	13742	13650
20-22 Jul-98	22-Jul-98	38.4-38.8°N	6	500	41	511	264	657	642	582	367	1261	1023
CBP	S1998203171459	37.8-38.4°N	4	3496	2071	3502	3189	3619	3608	3602	3319	3750	3744
		37.4-37.8°N	10	4342	2994	4354	4220	4412	4381	4423	4240	4475	4475
		<37.4°N	7	4221	3532	4223	4221	4223	4221	4223	4221	4223	4223
		Total	27	12559	8638	12590	11894	12911	12852	12830	12147	13709	13465
4-12 Aug-98	11-Aug-98	38.4-38.8°N	8	774	235	788	473	919	879	887	559	1039	1022
TIES	S1998223172028	37.8-38.4°N	9	3371	2190	3377	3220	3389	3340	3389	3258	3389	3389
		37.4-37.8°N	20	3055	2302	3055	3025	3061	3040	3061	3042	3061	3061
		<37.4°N	9	4261	3906	4261	4256	4261	4261	4266	4261	4266	4266
		Total	46	11461	8633	11481	10974	11630	11520	11603	11120	11755	11738
17-21 Aug-98	20-Aug-98	38.4-38.8°N	8	61	4	134	16	187	156	314	49	970	784

		<b>S1998232172739</b>	<b>37.8-38.4°N</b>	4	3293	1187	3349	2670	3615	3533	3661	3019	4156	4011
			<b>37.4-37.8°N</b>	10	4331	2931	4423	4305	4416	4404	4449	4340	4461	4461
			<b>&lt;37.4°N</b>	7	4189	3759	4189	4189	4185	4185	4185	4185	4185	4185
			<b>Total</b>	29	11874	7881	12095	11180	12403	12278	12609	11593	13772	13441
<b>12-15 Oct-98</b>	<b>14-Oct-98</b>	<b>38.4-38.8°N</b>	7	1502	123	1556	857	1662	1524	1665	1259	1674	1674	
CBP		<b>S1998287171637</b>	<b>37.8-38.4°N</b>	4	4492	3980	4493	4279	4502	4488	4376	4307	4376	4376
			<b>37.4-37.8°N</b>	10	4474	4455	4473	4473	4472	4472	4465	4452	4465	4465
			<b>&lt;37.4°N</b>	7	4294	4291	4294	4294	4294	4294	4294	4294	4294	4294
			<b>Total</b>	28	14762	12849	14816	13903	14930	14778	14800	14312	14809	14809
<b>12-15 Oct-98</b>	<b>16-Oct-98</b>	<b>38.4-38.8°N</b>	7	1099	99	1121	407	1303	1105	1262	500	1331	1331	
CBP		<b>S1998289170727</b>	<b>37.8-38.4°N</b>	4	4182	4013	4175	4136	4182	4182	4123	4081	4123	4123
			<b>37.4-37.8°N</b>	10	4294	4273	4294	4294	4294	4294	4288	4288	4288	4288
			<b>&lt;37.4°N</b>	7	4102	4102	4102	4102	4102	4102	4102	4102	4102	4102
			<b>Total</b>	28	13677	12487	13692	12939	13881	13683	13775	12971	13844	13844
<b>19-23 Oct-98</b>	<b>23-Oct-98</b>	<b>38.4-38.8°N</b>	7	1206	65	1296	865	1489	1192	476	460	476	476	
		<b>S1998296172327</b>	<b>37.8-38.4°N</b>	10	3926	2128	3890	3675	3911	3828	2389	2389	2389	2389
			<b>37.4-37.8°N</b>	7	3964	3946	3961	3961	3930	3925	3294	3289	3294	3294
			<b>&lt;37.4°N</b>	10	3153	3147	3116	3110	3124	3124	1575	1575	1575	1575
			<b>Total</b>	34	12249	9286	12263	11611	12454	12069	7734	7713	7734	7734
<b>11-13 Jan-99</b>	<b>11-Jan-99</b>	<b>38.4-38.8°N</b>	4	1547	405	1534	550	1685	1568	231	224	231	231	
CBP		<b>S1999011173720</b>	<b>37.8-38.4°N</b>	5	4517	3932	4511	4051	4498	4487	3792	3781	3792	3792
			<b>37.4-37.8°N</b>	10	4504	4504	4504	4504	4500	4500	4494	4494	4494	4494
			<b>&lt;37.4°N</b>	8	4296	4278	4295	4289	4296	4296	3722	3722	3722	3722
			<b>Total</b>	27	14864	13119	14844	13394	14979	14851	12239	12221	12239	12239
<b>16-18 Mar-99</b>	<b>18-Mar-99</b>	<b>38.4-38.8°N</b>	7	1128	33	1444	1081	1569	1478	1804	1412	1866	1866	
CBP		<b>S1999075172420</b>	<b>37.8-38.4°N</b>	4	4293	648	4321	3916	4586	4458	4701	4306	4774	4774
			<b>37.4-37.8°N</b>	10	4723	3797	4723	4632	4715	4684	4715	4639	4715	4715
			<b>&lt;37.4°N</b>	7	4405	4405	4405	4405	4405	4405	4404	4404	4404	4404
			<b>Total</b>	28	14549	8883	14893	14034	15275	15025	15624	14761	24671	26912
<b>19-23 Apr-99</b>	<b>25-Apr-99</b>	<b>38.4-38.8°N</b>	8	1252	230	1241	442	1474	1439	1154	799	1210	1210	
TIES		<b>S1999115172629.</b>	<b>37.8-38.4°N</b>	8	3681	1019	3669	2742	4144	4073	3984	3458	4136	4136

		<b>37.4-37.8°N</b>	12	4307	3213	4303	4218	4416	4410	4434	4293	4530	4530
		<37.4°N	12	4200	4170	4200	4200	4195	4195	4185	4185	4185	4185
		<b>Total</b>	40	13440	8632	13413	11602	14229	14117	13757	12735	14061	14061
<b>26-29 Jun-99</b>	<b>26-Jun-99</b>	<b>38.4-38.8°N</b>	7	835	722	835	750	891	891	879	798	919	919
<b>TIES</b>	<b>S1999177171658</b>	<b>37.8-38.4°N</b>	8	4375	4102	4371	4220	4397	4392	4352	4285	4373	4373
		<b>37.4-37.8°N</b>	15	4626	4409	4619	4585	4626	4626	4619	4609	4619	4619
		<37.4°N	14	4140	4134	4134	4134	4140	4140	4134	4134	4134	4134
		<b>Total</b>	44	13976	13367	13959	13689	14054	14049	13984	13826	14045	14045